Modeling and Simulation Development Of Very High Frequency Digital Link Mode 3 in OPNET

Integrated CNS Technologies Conference & Workshop

Washington DC

April 29 - May 2, 2002

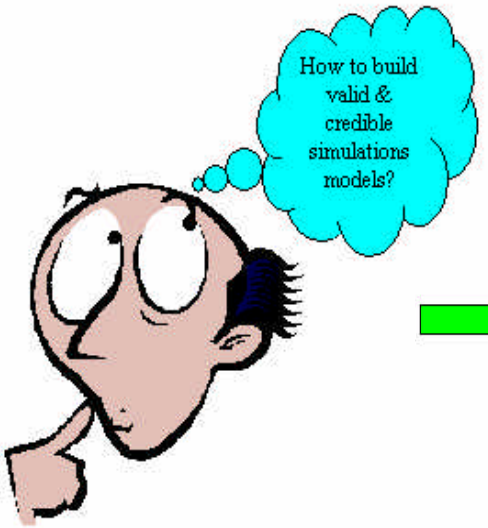
Thanh C. Nguyen, Analex Corporation

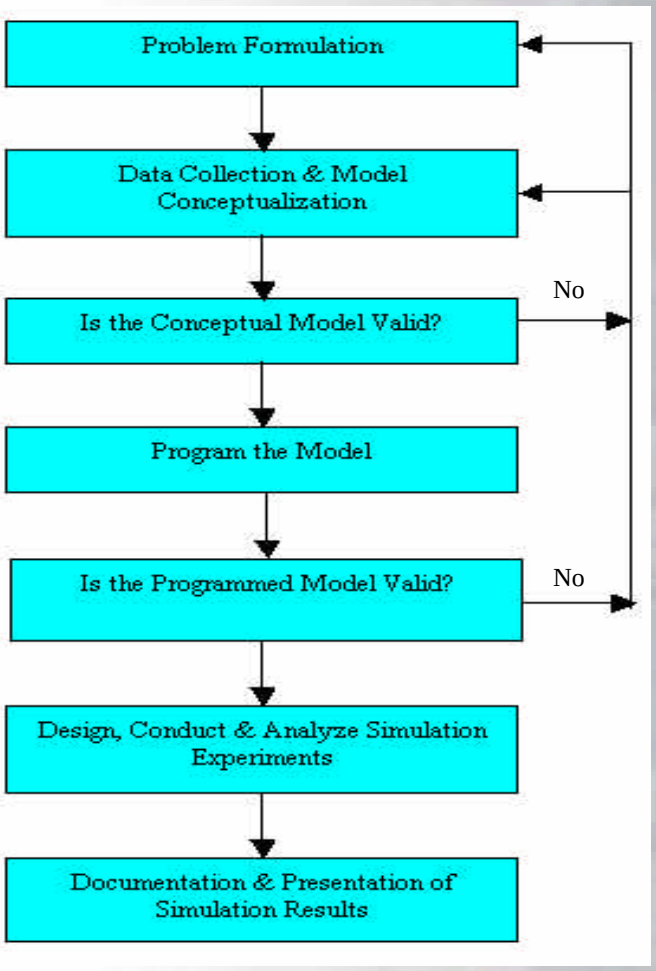
Steven W. Mainger, NASA Glenn Research Center

UNDER DEVELOPMENT ...

- A set of VDL Mode 3 Simulation Models
- Comprehensive & configurable to handle air/ground data & voice (developing from the ground up)
- Recognize and support VDL Mode 3 system configurations in SARPs
- Ultimately, to be used for validation of future candidate architectures of aeronautical wireless and mobile communication network

Approach


How to build valid & credible simulations models?

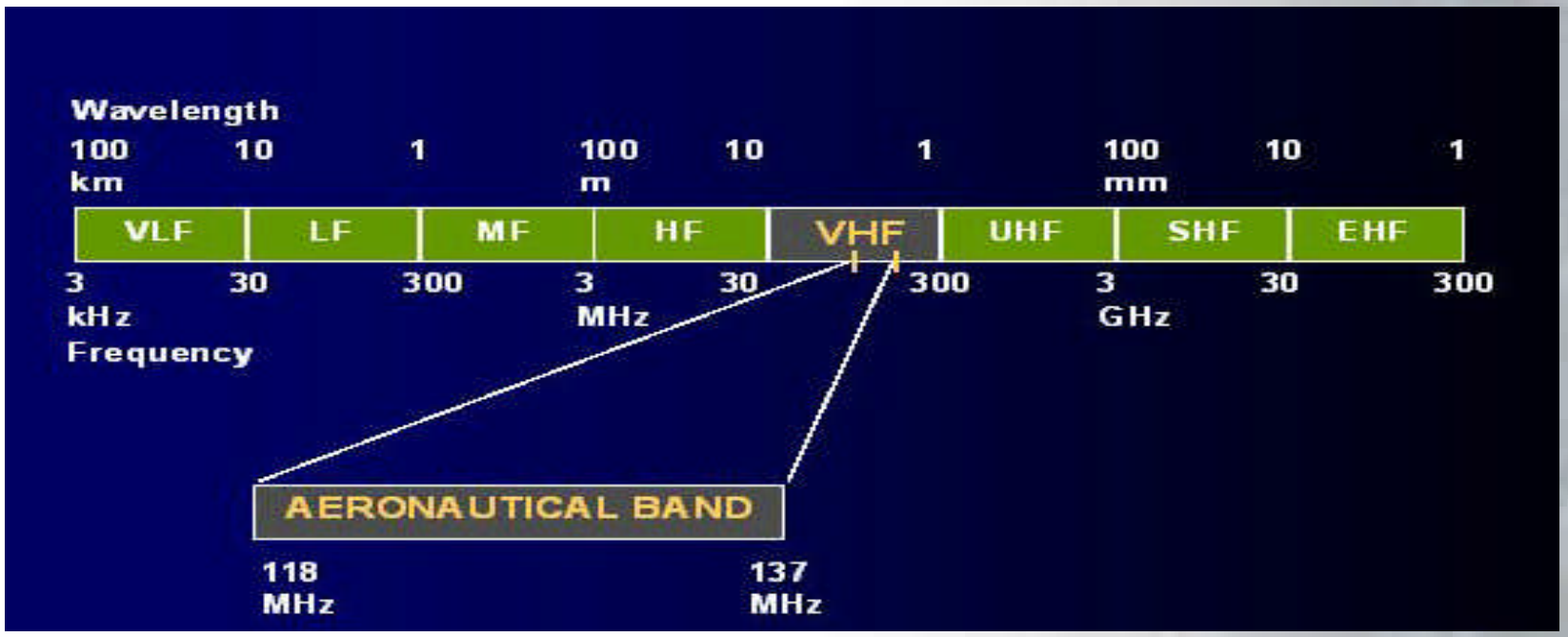

Problem Formulation
Data Collection & Model Conceptualization
Is the Conceptual Model Valid?
No
Program the Model
Is the Programmed Model Valid?
No
Design, Conduct & Analyze Simulation Experiments
Documentation & Presentation of Simulation Results

VHF Communications Overview

- A QUICK REVIEW OF:
  - Electromagnetic spectrum
  - Aeronautical VHF band
  - VHF Digital Link (VDL)

Electromagnetic Spectrum

- VHF frequency range: 30 - 300 MHz
- Aeronautical applications: 118 - 137 MHz (frequency range at which there is line-of-sight propagation or range of signals limited by obstacles such curvature of earth, terrain shadows and building shadows).



Aeronautical VHF Band

Year	Aero. Mobile Band	Channel Spacing	Note
Before 1958	118 – 132 Mhz	200 kHz	Initial band for airborne comm.
1958	118 – 132 Mhz	100 kHz	Number of channels doubled
1959	118 – 136 Mhz	50 kHz	4 Mhz added to top end/channels doubled
1974	118 – 136 Mhz	25 kHz	Number of channels doubled
1979	118 – 137 Mhz	25 kHz	1 Mhz added to top end/40 channels added
1999	118 – 137 Mhz	8.33 kHz	Only in European upper airspace

- Total number of 25 kHz channels: 760

- Further subdivision of 25 kHz spaced channel is impractical to send data over 8.33 kHz channel due to low bit rate
- Alternative to further subdivision of VHF spectrum is TDMA

VHF Digital Link

- ICAO recognized the need for VHF Digital Link (VDL) and established standards for future VHF digital mobile communications
- ICAO defined VDL as a constituent mobile subnetwork of Aeronautical Telecommunication Network (ATN)
- There are 4 VDL Modes:

	ATN Data	Non-ATN Data*	Voice	Status
VDL Mode 1	✓			SARPs incorporated into Annex 10 in November 1997
VDL Mode 2	✓			SARPs incorporated into Annex 10 in November 1997
VDL Mode 3	✓		✓	SARPs approved at AMCP/7
VDL Mode 4	✓	✓		SARPs approved at AMCP/7

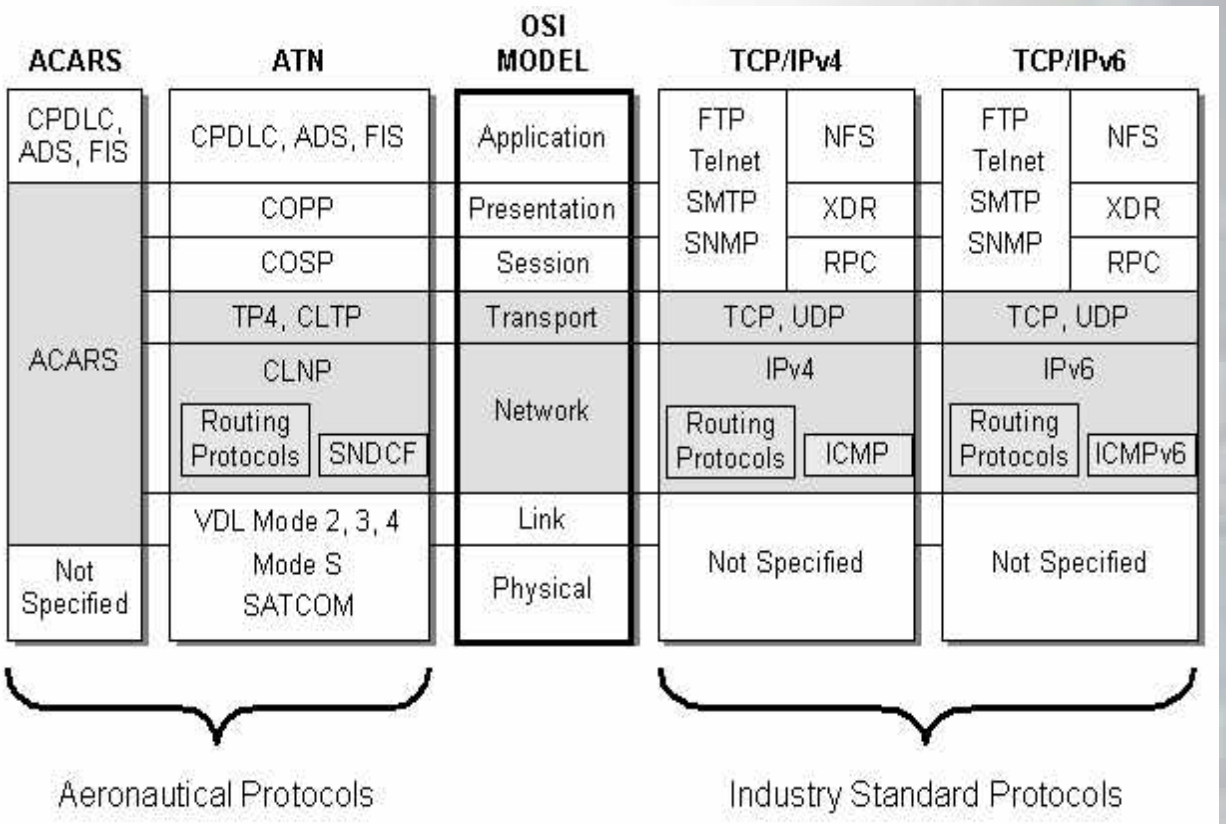
* Non-ATN data includes ADS-B application & air-to-air communications

VDL Mode 3

- Originally proposed by FAA to ICAO in May 1994
- ICAO standards (SARPs) recommended for publication at AMCP 7 in early 2000
- VDL Mode 3 provides both data & digital voice services
- 4 logical channels in 25 kHz frequency assignment
- Each logical channel can be allocated to voice or data (several static & one dynamic configuration)
- Based on D8PSK modulation at 31.5 kbps (half-duplex burst rate for each 25kHz channel)
- TDMA access controlled centrally from ground station
- System applies “user groups”. For example,
  - a group of ground & airborne users
  - a controller and its controlled aircraft

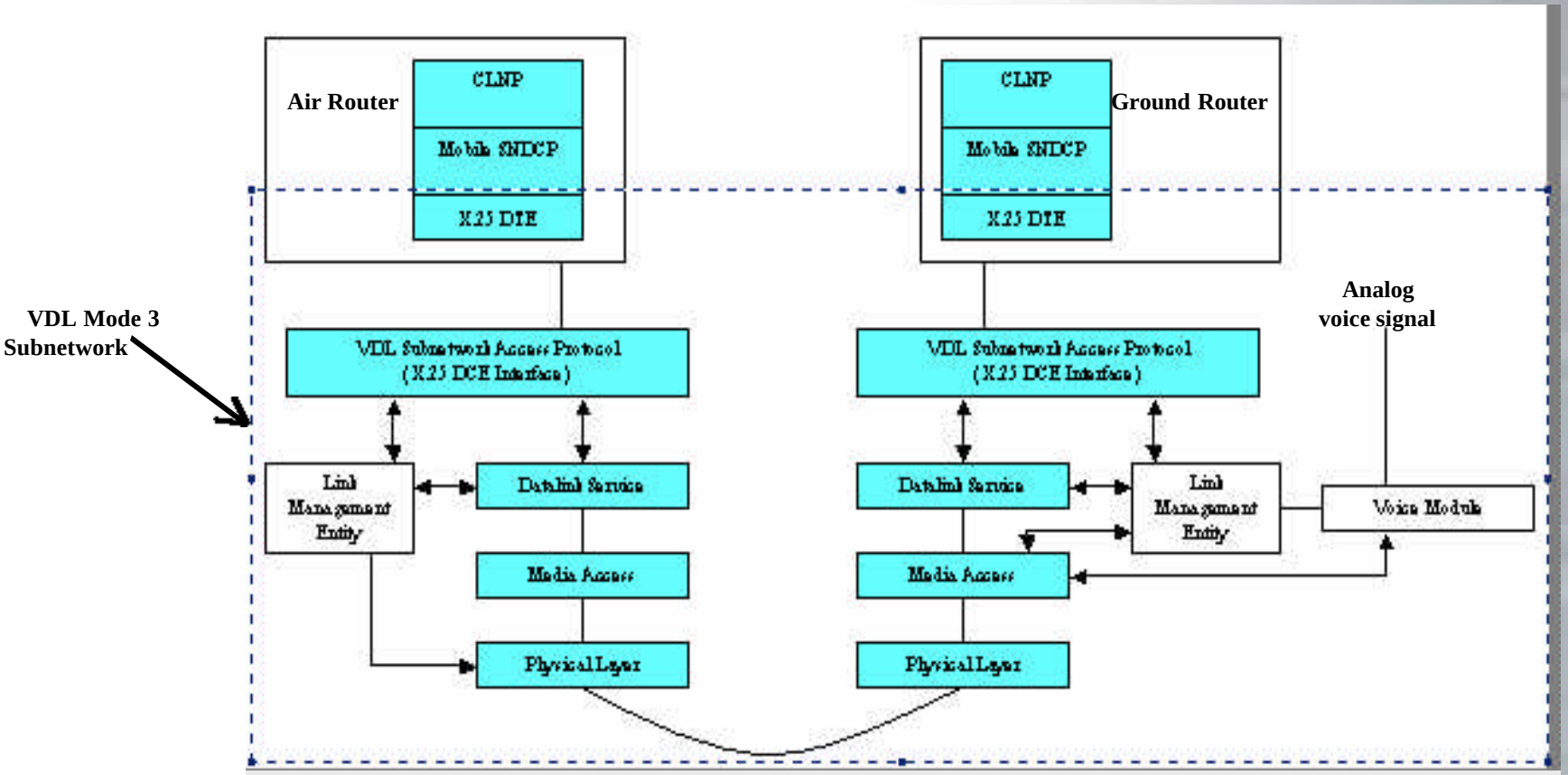
Aeronautical Telecommunication Network (ATN)

- Primarily ISO protocols: CLNP (ISO 8473), IDRP (ISO 10747), COTP (ISO 8073), and ES-IS (ISO 9542).



Courtesy of CNS, Inc. **Protocol Stack Comparisons**

Subnetwork Architecture



VDL Mode 3 Subnetwork Architecture

VDL Mode 3 Traffic Model

- Data link message traffic model used in the VDL-3 subnet simulation is based on FAA Data Link Operational Requirements Team (DLORT) air/ground data communications traffic model. (Also used by MITRE).

DLORT A/G Data Communications Demand Model

Message Distribution	Priority	Uplink		Downlink	
		Average message rate in steady state	Average message size in bits	Average message rate in steady state	Average message size in bits
Exponential inter-arrival with Poison message size	High	0.017	137	0.024	110
	Medium	0.0017	198	0.0008	100
	Low	0.001	2400	0.002	2400
Constant (Notes 5 & 6)	Low	0.017	3325	0.0033	1760

Notes:
1. Rates are in number of messages per second per aircraft
2. 31 octets of protocol header are added to each message in simulation
3. Each message is acknowledged at Data Link Sublayer except broadcast
4. ACK of uplink message uses downlink M subchannels, ACK of downlink message requires 8 octet conveyed in the V/D (data) subchannels
5. Broadcast service is provided for constant uplink messages
6. Periodical fixed size downlink meteorological observations
7. All traffic collectively represents a Load Factor of 1

VDL-3 Subnet Simulation Models

- OPNET tools used in this work are Modeler and Modeler Radio Module.
- VDL-3 subnet simulation models are OPNET network models emulating protocol operations described in VDL Mode 3 SARPs
- Procedures for generating corresponding TDMA timing reference points in each VDL-3 configuration were used to provide basic clock ticks for simulation of TDMA protocol cycles
- Prioritized queues maintained at DLS and MAC sublayers for data slots reservation, message segmentation, multiplexing, transmission, and acknowledgment.
- VDL-3 subnet simulation models consists of mobile radio nodes (aircrafts) and fixed radio nodes (ground stations)

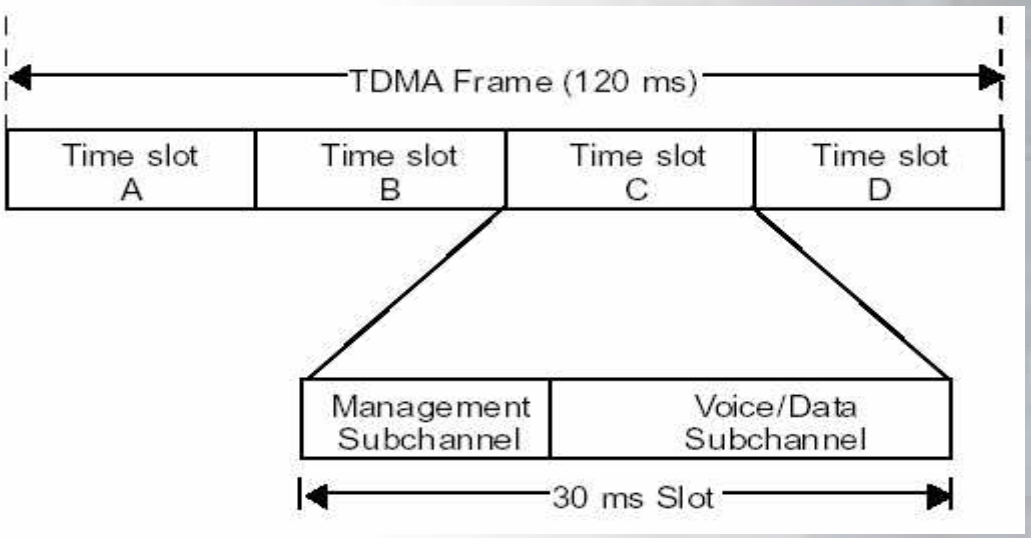
Process Modeling

- Process modeling: OPNET processes or state machines included in fixed and mobile nodes in VDL-3 subnet simulations are:
  1. **Packet generator (source)**
  2. **Packet absorber (sink)**
  3. **MAC TDMA clock state machine for specific Mode 3 configuration (4V, 3V1D, 2V2D, 3V1D, &3T)**
  4. **MAC state machine**
  5. **MAC priority queues**
  6. **Data Link Service/Link Management Entity (DLS/LME) state machine**
  7. **Radio, transmitter, and antenna**

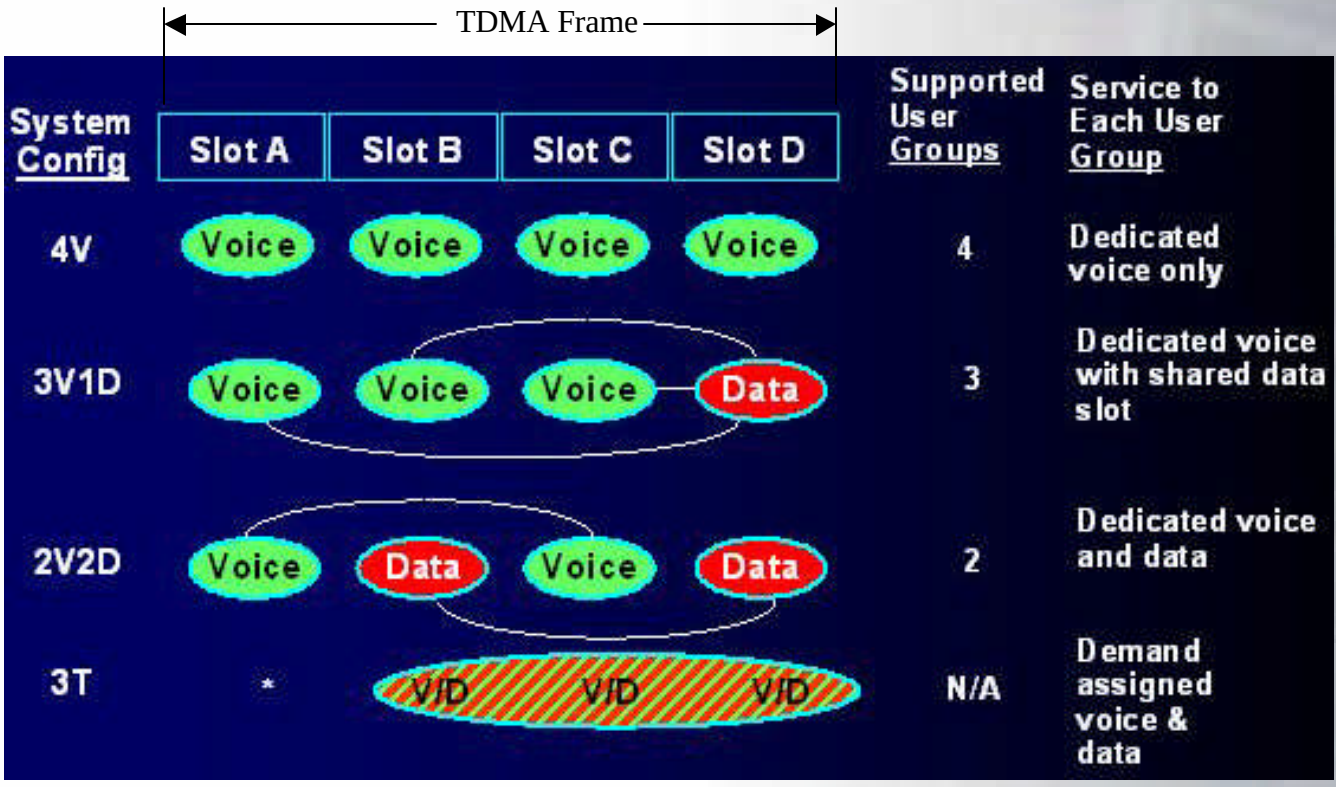
- All processes are either interrupt or event driven
  - **interrupts are TDMA clock ticks**
  - **events are packet arrival and departures**

Physical & MAC Layers Simulation

- VDL-3 physical layer parameters include: transmitter power, VHF frequency, D8PSK modulation/demodulation (d8psk.md.m), number of aircrafts (up to 160), airspace size (200 nmi or less), and average aircraft altitude (25,000 ft). Radio line of sight $R = 1.225H^{1/2}$.
- VDL-3 MAC sublayer simulation consisting of: a TDMA clock simulation, a MAC protocol state machine, and priority queuing simulation
- VDL-3 TDMA cycle looks like this:



VDL-3 System Configurations



Note: Each configuration differs depending on functional allocation of individual Logical Burst Access Channel (LBAC).

State Transitions

- TDMA clock (interrupts)
- Ground radio protocol
- Airborne radio protocol
- Data Link Service (DLS) sublayer
- DLS/LME link establishment
- DLM for frame grouping and priority queuing
- DLE peer-to-peer Acknowledged Connectionless Data Link (A-CLDL) protocol

Glenn Research Center

Analex Corporation

VDL-3 Simulation Software Demo (OPNET) ???

Future Plans

- VDL Mode 3 subnet data link Performance baselines.
- Validation of VDL Mode 3 network and protocol models.
- Develop Integrated ATN-VDL Mode 3 Model, with realistic flight profile & trajectory

Glenn Research Center

Analex Corporation

Thank You!